Chapter 23: Circuits

Section 23.1: Circuit Elements and Diagrams

Symbols for Electric Circuits

- Standard symbols are useful for wiring diagrams
- Wiring diagrams are necessary for designing and building
- Everybody agrees on the symbols, everybody builds the same circuit

Analyzing a Simple Circuit

- A circuit requires a complete closed path containing a voltage source and whatever additional devices
- You can have multiple voltage sources and multiple devices
- Assume that the wire does not dissipate any of the energy
- This means the only voltage drops will occur at the resistors

Section 23.2: Kirchhoff's Laws

Kirchhoff's Junction Rule

- Total current in = total current out, or: $I = I_1 + I_2 + \cdots + I_n$
- This is basically charge conservation: you can't lose the electrons!

Kirchhoff's Loop Rule

- The algebraic sum of the changes in electric potential (voltage) around any closed circuit loop is zero
- This is fundamentally a statement of energy conservation! You can't get back what you didn't put in

Watch Your Signs!

- Sign convention is probably the most difficult thing about Kirchhoff!
- The potential change across a resistor is (–) if moving in the direction of the current: $\Delta V = -IR$
- If moving across a resistor opposite the direction of the current, potential change is (+): $\Delta V = +IR$
- Potential difference across battery terminals from negative to positive is (+): $+V$
- Potential difference across battery terminals from positive to negative is (–): $-V$

Section 23.3: Series and Parallel Circuits

Circuits in Series

- Series = "and"
- One closed path: same current flows through device 1 and device 2, and however many devices are wired
- Dependent: every device depends on every other device in the circuit (all must be on or none can be)
- More devices = more total resistance
- For a given voltage source, increasing the number of devices decreases the current draw

Resistors in Series

- Current is common: $I_1 = I_2 = \cdots = I_n = I$
- Voltage is shared: $V_1 = IR_1, V_2 = IR_2, \cdots, V_n = IR_n$ and $V = V_1 + V_2 + \cdots + V_n$
- Using Ohm's Law: $R = R_1 + R_2 + \cdots + R_n$ (notice the "and:" R_1 and R_2 and …)
- Adding series resistors decreases total current draw

Circuits in Parallel

- Parallel = "or"
- Multiple possible pathways: closed path through device 1 or device 2
- Independent: each device has its own path, and each device can be on or off regardless of the other devices
- More devices = more potential pathways for current flow
- For a given voltage source, increasing the number of devices increases the current flow

Resistors in Parallel

- Voltage is common: $V_1 = V_2 = \cdots = V_n = V$ = battery voltage
- Current is shared: $I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, \cdots, I_n = \frac{V}{R_n}$ and $I = I_1 + I_2 + \cdots + I_n$
- Using Ohm's Law: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$
- Adding parallel resistors increases total current draw

How Is Your House Wired?

- Does every appliance have to be switched on for any appliance to work? Or can you turn one device on or off without affecting other devices?
- A household wired in series is obviously a bad idea
- Your household wiring will actually consist of several independent parallel circuits (when you throw the breaker in the dining room, the front entry light goes out, but the rest of the house is unaffected)

Pick The Brighter Bulb!

- Wire a 60W bulb by itself to a 120V voltage source: $R_1 = \frac{V^2}{P} = 240\Omega$
- Now do the same with a 100W bulb: $R_2 = \frac{V^2}{P} = 144\Omega$

- Put the bulbs in series! total $R = R_1 + R_2 = 384\Omega$, and $I = 0.31\text{A}$
- This makes $P_1 = I^2R_1 = 23\text{W}$ and $P_2 = I^2R_2 = 14\text{W}$
- Now put them in parallel! No math required: the 100W bulb is brighter

Section 23.4: Measuring Voltage and Current

Ammeters

- Ammeter: device to measure current
- Hypothetical $R = 0$ so as not to create a voltage drop
- Wire ammeters in series with the device you are analyzing (measure "current through")

Voltmeters

- Voltmeter: device to measure potential difference
- Hypothetical $R = \infty$ so as not to draw current
- Wire voltmeters in parallel with device you are analyzing (measure "voltage across")

Section 23.5: More Complex Circuits

Section 23.6: Capacitors in Parallel and Series

Capacitors in Series

- Series means $V = \sum V_n$
- $\frac{1}{C} = \sum \frac{1}{C_n}$

Capacitors in Parallel

- Parallel means $V_1 = V_2 = \cdots = V_n = V$
- $C = \sum C_n$

Section 23.7: RC Circuits

What's the Point?

- Sometimes you don't want the current to be constant
- What if you want bursts of current, or a regular on-off cycle?

Discharging a Capacitor

- Notice that there's no battery in this circuit
- How did that capacitor get its initial charge?
- Maybe we should talk about charging the capacitor first

Charging a Capacitor

- This makes MUCH more sense!
- Start by connecting the battery
- Current will flow, but not at a constant rate
- As charge accumulates on the capacitor, it takes more work to add each subsequent charge

Discharging a Capacitor

- Now we can flip the switch to cut the battery out of the circuit
- The voltage across the capacitor now drives a current in the opposite direction
- Same exponential curve, only decreasing

Time Constant

- $\tau = RC$
- High τ means it takes a long time to charge or discharge
- Because the curve is exponential, the first few τ give greatest effect
- After about 5τ, you can say the capacitor is fully charged (or discharged)